A Materials and Defect Simulator for Calibrating Ultrasonic Equipment Used in Nondestructive Testing or Inspection

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ABSTRACT

An ultrasonic Electronic Test Block (ETB) has been devised for use in calibrating ultrasonic nondestructive tests and equipment. The ETB is similar to a transponder. A device sensitive to ultrasonic waves receives the acoustic signal emitted by any ultrasonic equipment. This received signal is then electronically processed and re-emitted in such manner as to appear to be an echo, as from a standard reference block. Both vertical and horizontal linearity on the cathode-ray-tube screen as well as resolution can be determined at the testing site, rather than in the laboratory as is presently necessary using standard reference blocks. The use of the ETB as a flaw size simulator is being further investigated; this use is feasible if the ETB can be used to measure the active area and the operating frequency of the acoustic signal, since the echo characteristics depend not only on the flaw parameters but also on the acoustic signal parameters.

PROBLEM STATUS

This is an interim report on this program. The work is continuing on this phase of the problem.

AUTHORIZATION

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A MATERIALS AND DEFECT SIMULATOR FOR CALIBRATING ULTRASONIC EQUIPMENT USED IN NONDESTRUCTIVE TESTING OR INSPECTION

INTRODUCTION

Effective inspection of structural materials by means of ultrasonic waves is based on the detection of certain abnormal transmission characteristics for the medium under observation. These transmission characteristics in part can be listed as: attenuation; scattering due to inhomogeneities or grains; reflection from flaws, voids, or cracks; sonic beam bending; and mode conversion.

The equipment operator can provide himself reference displays for routine comparison by applying the probe (transducer) at intervals to test specimens fabricated of the same type of structural material being inspected and containing typical examples of the defect categories anticipated. Additional test blocks can serve to calibrate the coordinates on the cathode-ray-tube screen so that meaningful inferences regarding size and location of an observed defect are possible. Thus many test blocks are needed to effectively equip an inspection facility.

Most of these reference signals can be adequately simulated by electronic means. A single, compact portable standard with adjustable parameters which would replace a multitude of cumbersome passive test blocks is highly desirable. Such a device, an Electronic Test Block,* has been developed, and a preliminary model will be described that performs the coordinate calibration. Further functions, for example, flaw size simulation, will be included in future models.

THE ELECTRONIC TEST BLOCK

Basic Operation

The Electronic Test Block (ETB) behaves in some ways as a transponder. In its simplest mode of operation it senses and measures the amplitude of the transmitted ultrasonic pulse from the probe transducer of the inspection equipment. After a suitable delay it sends back an ultrasonic pulse, with an amplitude proportional to the transmitted pulse. In this way it simulates a passive test piece (Fig. 1) reflecting from its built-in defect only that portion of the transmitted pulse which has impinged on it. Since the ETB is electronic, the factor or proportionality is readily adjustable. Hence we have, in effect, an adjustable test piece. Figure 2 depicts the basic mode of operation.

Electronic Considerations

Figure 3 shows the main electronic considerations of the ETB. An input/output network (upper left) is required to cope with the wide range of voltages met at the ETB's standard transducer. Input signals from impinging ultrasonic pulses may vary by two decades (in the present design from 0.2 to 20 volts). To produce the output ultrasonic

*Subject of NRL patent docket 8105, April 18, 1967.

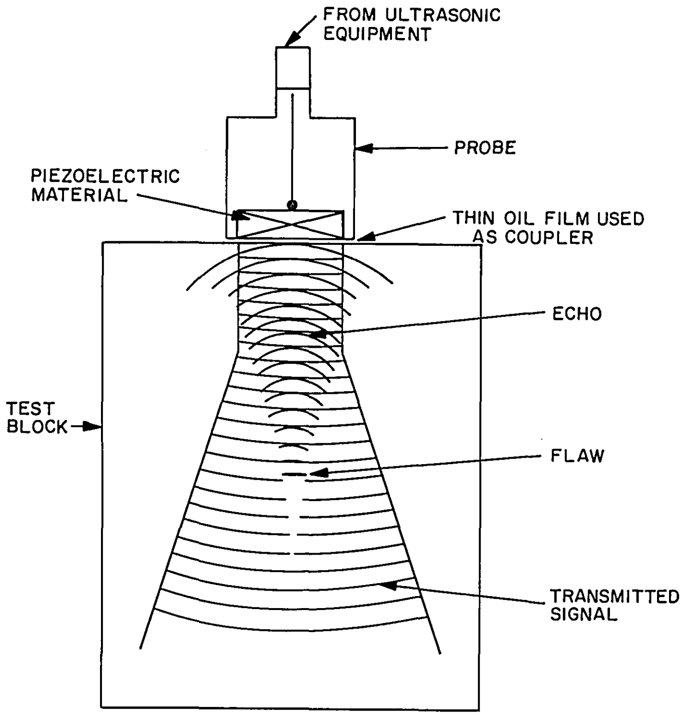

Fig. 1 - Passive test piece

pulses a maximum of 150 volts is used to excite the standard transducer. An attenuator is therefore required as protection for the noninverting amplifier (A1) against the large signal returned by the ETB from its avalanche pulsers. Limiter diodes (D1 and D2) serve to further protect the more sensitive amplifiers (A2 and A3) in the absolute value amplifier (upper right), which is the heart of the ETB. An input signal received from the noninverting amplifier (A1) is sent through an inverting amplifier (A2) and a noninverting amplifier (A3) to two voltage comparators (VC2 and VC3). The voltage comparators act as follows: When at least one of the input signals (V_{in}) is greater than the reference voltage (V_{ref}), the level shifter and driver circuit will increase the charge on the capacitor (C1). This voltage will increase V_{ref} until it is equal to the largest V_{in}, at which point equilibrium will be established, and a voltage proportional to the maximum absolute value of the peak voltage at the input is stored on the capacitor (C1). Dual voltage comparators are required, since the transducer peak voltage may be positive or negative depending on the electrical polarity (Fig. 4).

The charge deposited on capacitor C1 is brought to the input side of VC4 in the control voltage network. This network is akin to the absolute value amplifier with the exception that the output of the level shifter and driver is approximately 150 volts. The output of the circuit is controlled by the potentiometer (R1), which is part of a voltage divider circuit. In this manner the high voltage available to the standard transducer is made proportional to the small input signal received. Potentiometer R1 becomes the variable "flaw size" control of the ETB.

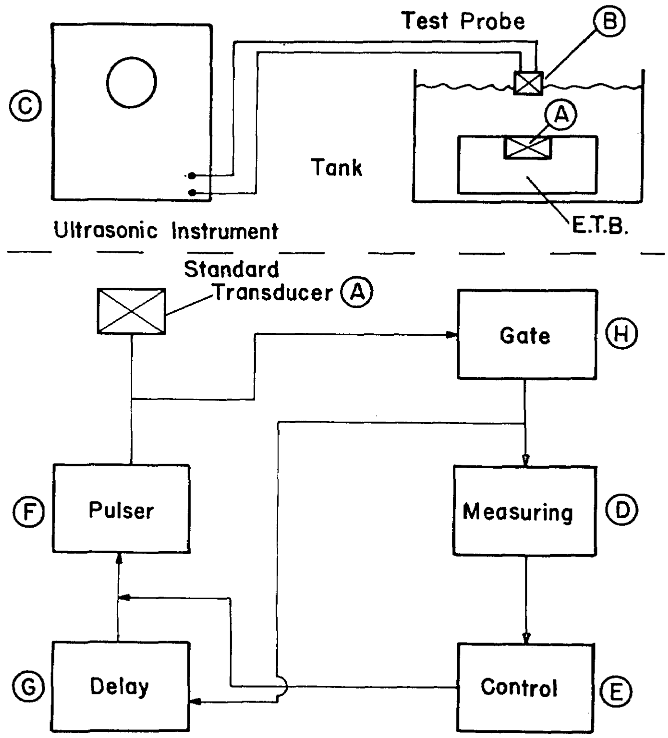

Fig. 2 - Basic mode of operation of the electronic test block in simulating passive test blocks such as shown in Fig. 2. The sensing element (A), usually a piezoelectric material, receives the transmitted acoustic pulse (B) from any given ultrasonic inspection equipment (C). This pulse is measured (D), and a signal level is brought to a control circuit (E). Here it proportionally adjusts the amplitude of the variable pulser (F) and triggers the signal to be returned by the sensing element (A). The delay circuit (G) controls the timing of the return echo. Gate (H) prevents the returned pulse from reentering the measuring circuit.

Four return echoes are produced for each received signal. Each pulser has its own adjustable delay circuit and amplitude control. However, at all times, the return signal is proportional to the sensed input voltage. To fire the avalanche transistor at the wide range of voltages required, the circuit in Fig. 5 is used in each of the four pulsers. The output charge from the high-voltage network is placed on capacitor C2, and the avalanche transistor is brought near the threshold firing level. Diode D3 effectively isolates the avalanche voltage from the voltage of C2, the voltage to the standard transducer. A small trigger pulse, at the desired time, fires the avalanche, which discharges itself as well as the stored charge on C2. Such action permits the standard transducer to be shock-excited by a wide range of voltages.

A gate is necessary to keep the completed ETB circuit from retriggering itself. This is accomplished by the timing circuit, which blanks out the three voltage comparators (VC1, VC2, and VC3) for a specified length of time. The trigger voltage to fire the avalanches comes from the output of the main delay circuit.

TEST RESULTS ON THE PRELIMINARY ETB MODEL

Linearity and repeatability are of prime importance in the operation of the ETB. Extensive measurements of these factors were made using the test configuration shown on Fig. 6. A Tektronix 556 dual-beam oscilloscope with a Type W voltage comparator was used. The variable pulse applied to the probe was generated by the pulsed RF mode of an Arenberg PG-650-C pulsed oscillator, a Hewlett-Packard 212A pulse generator with variable pulse width, or a pulser of our own design similar to the ETB pulsers. Peak-to-peak voltages were measured in this test series.

Figures 7 and 8 show the linearity of the ETB response. The graph in Fig. 7 records the voltage generated by the probe which has received the mechanical waves generated by the ETB's standard transducer as a function of the voltage received by the ETB from its standard transducer (mechanical waves of varying intensity have impinged on the standard transducer, and a voltage is generated by that transducer). The curve is fitted by the least-mean-square method. Figure 8 shows the total response curve of the ETB (voltage applied by the ETB's avalanche pulsers versus the voltage applied to the test probe). A final graph (Fig. 9) depicts the response of the same probe used in Figs. 7 and 8 to a standard flaw built into an aluminum test piece.

From these graphs it is evident that a dynamic range of two decades has not been met by this preliminary model. Such requirement will be achieved in the next model. Although the least squares line on the graph in Fig. 9 does not go through the origin, the last few points appear to curve toward that point. Such a discrepancy occurs because peak-to-peak voltages were measured rather than the actual charge on the transducer.

CALIBRATION OF ULTRASONIC EQUIPMENT BY THE ETB

Before commercial ultrasonic equipment can be used to meaningfully infer the size and location of an observed defect, the coordinates on the cathode-ray-tube screen must be calibrated. The ETB provides this calibration. For vertical linearity (size information) four pulses are returned by the ETB for each pulse received. These pulses have amplitudes such that each is one-half of its predecessor (ratios of 8:4:2:1) and span the amplitude level to be used during inspection procedures. By observing the four echoes on the screen one can determine if their ratios are 2:1. Such a system is accurate, easy to use, and more convenient than the current test procedures, which are presently done in the laboratory rather than at the test site. An ETB examination is performed under actual test conditions, a very difficult feat for the conventional test.

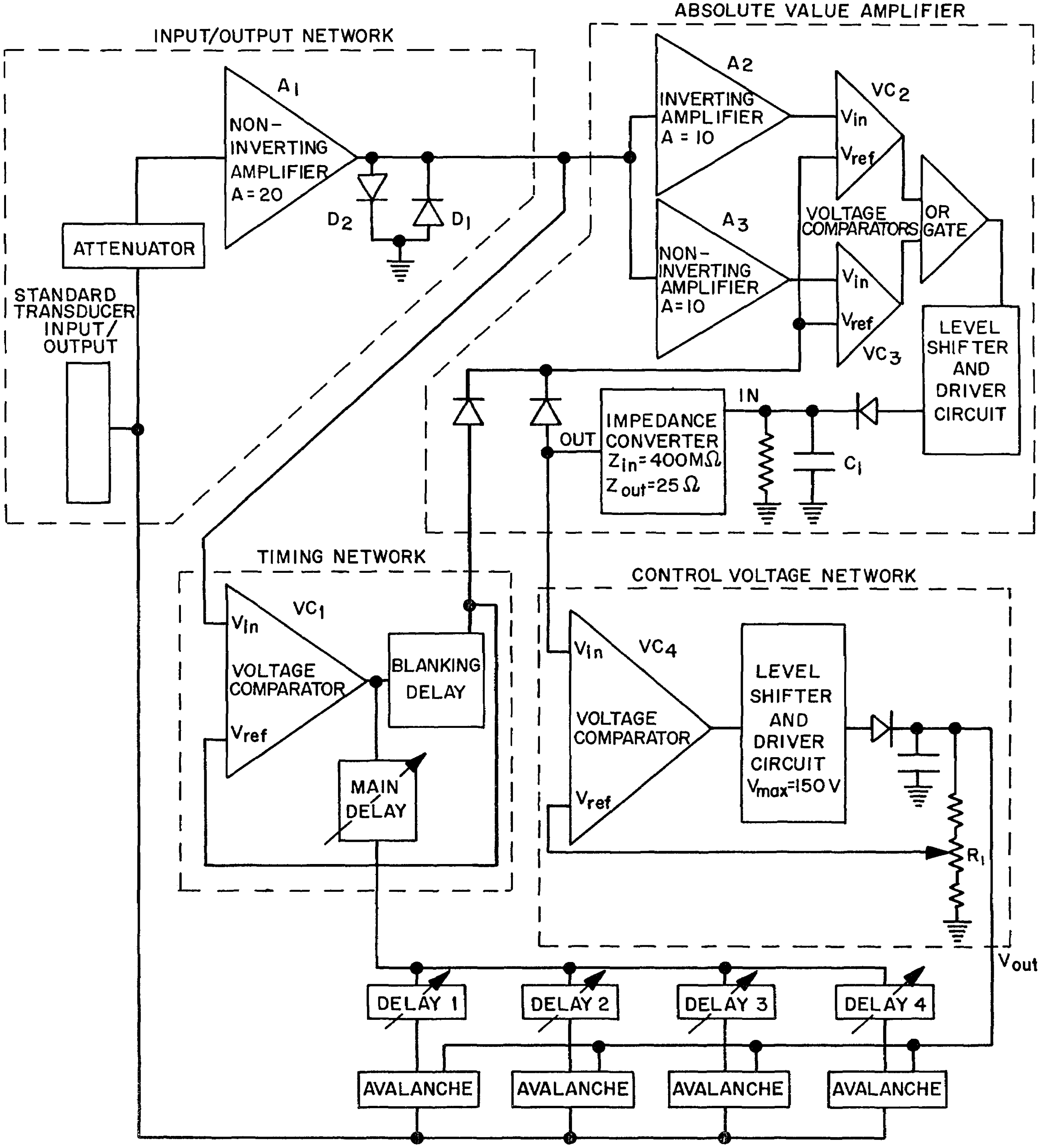

Fig. 3 - Electronic test block

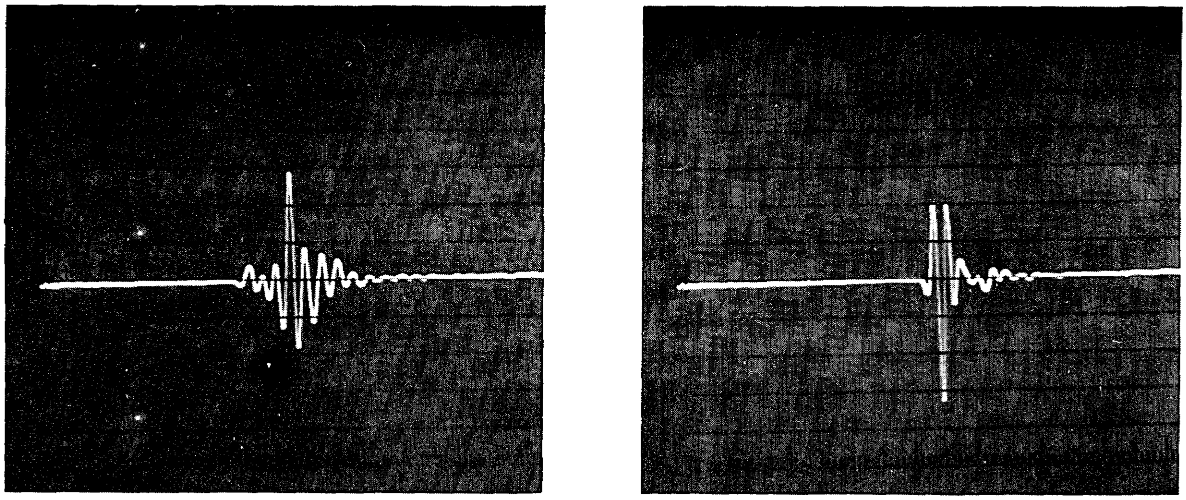

Fig. 4 - Input signal from the transducer

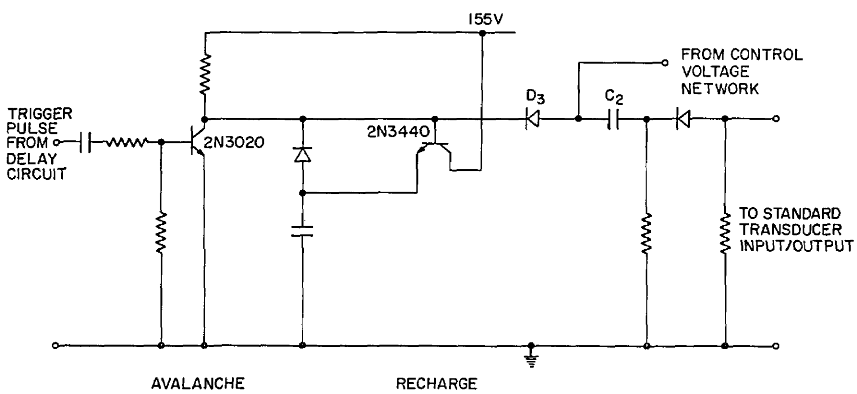

Fig. 5 - Circuit used for each of the four avalanche pulsers

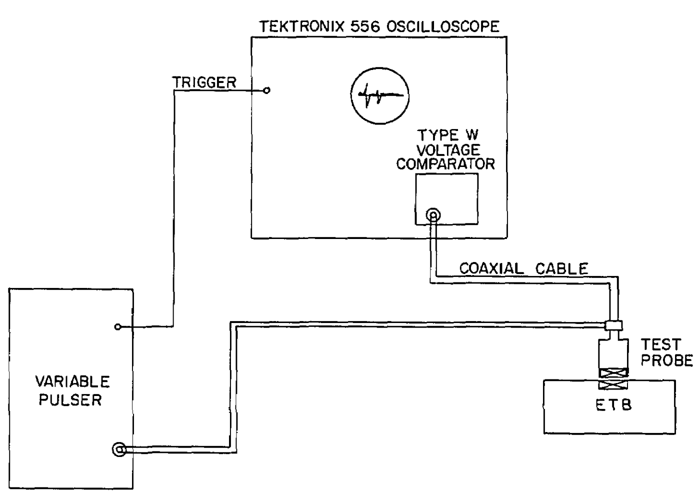

Fig. 6 - Test setup

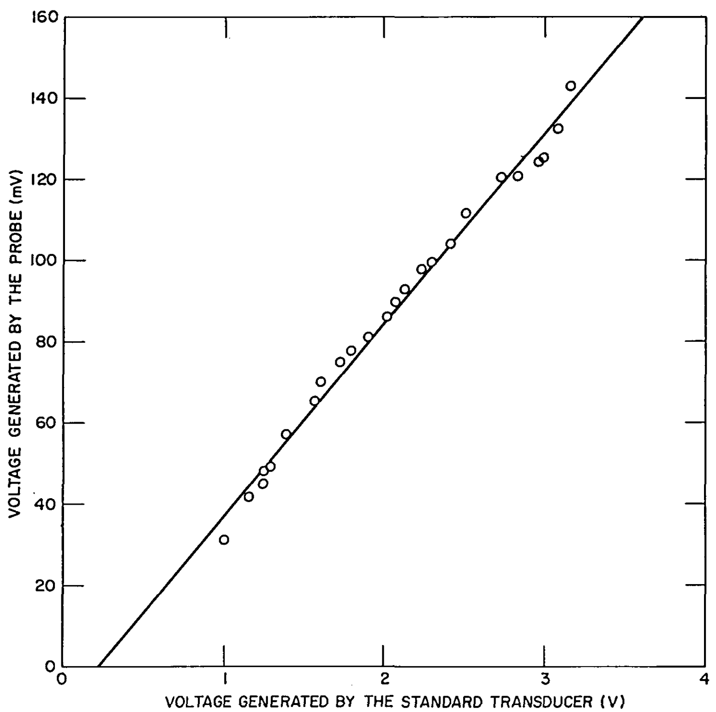

Fig. 7 - Linearity between the voltage generated by the probe upon receiving the mechanical waves put out by the standard transducer as the output of the ETB and the voltage generated by the standard transducer as the ETB input upon receiving mechanical waves of various intensity

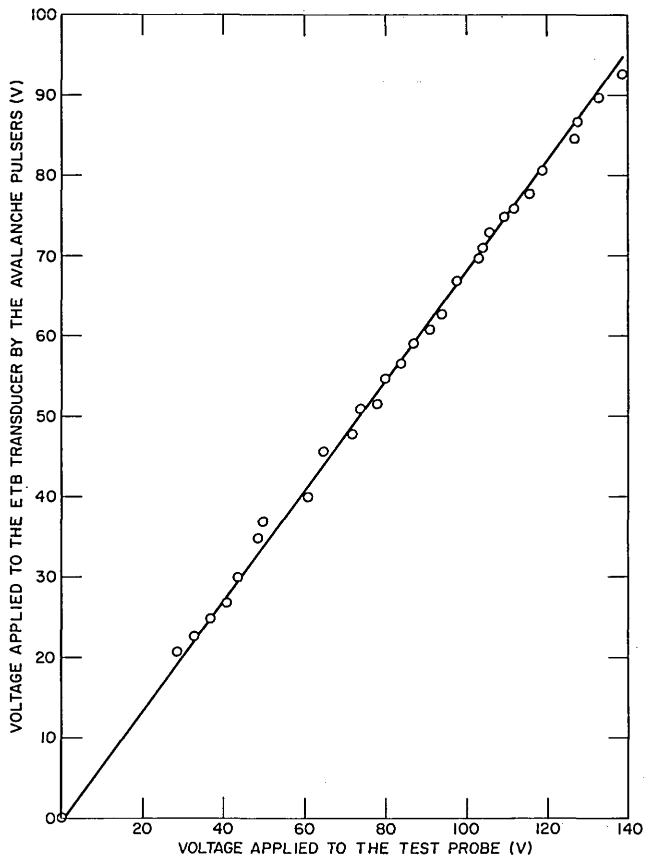

Fig. 8 - Linearity between the voltage applied to the standard transducer as the ETB output and the voltage applied to the test probe to produce the input to the ETB

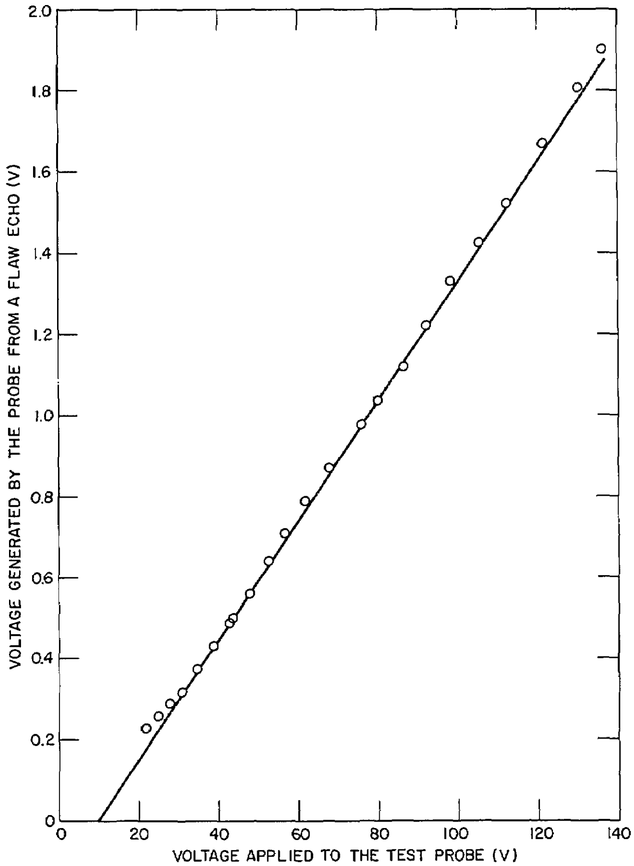

Fig. 9 - Response of the same probe used in Figs. 7 and 8 to a standard flaw in a test block (a 1/4-inch-diameter through hole perpendicular to the probe)

Time-base linearity is checked by the same four pulses. The time relationship between pulses is accurately set in accordance to the test specifications. Observing the separation of these pulses as they appear on the screen and comparing them to the graticule markings, the linearity of the time base is ascertained.

In addition to checking the linearity of the coordinates, the resolution or resolving power must be tested.

Resolution from the ultrasonic standpoint refers to temporal separation (depth or transit time of the sonic pulse in the medium). Two basic physical configurations to consider when testing the resolution are the ability to resolve two signals of greatly different amplitudes and the ability to resolve two signals nearly equal in amplitude. As shown in Fig. 10 the search for a small flaw near the front or back surface of a test specimen will produce signals with large amplitude differences. Figure 11 depicts some instances in which signals to be resolved are of equivalent signal strength. Since resolution is a time-dependent variable, the time sequence of events must be considered along with the relative signal strengths (Fig. 10).

Two of the four pulsers from the ETB are disabled when testing the resolving capability of an ultrasonic instrument. The output of the two pulsers is set so that they closely approximate the magnitudes of the echoes from the objects to be resolved. Changing the time delay between these two pulses gives an indication of the maximum resolving capability for that particular system under the set conditions. The multiple pulsers of the ETB can be adjusted to have zero delay (be superimposed). This approach provides an accurate analysis of the resolution capabilities of the ultrasonic equipment. The pulser, probe, and receiver are examined as a unit in a manner which is simpler, more efficient, and less time consuming than is possible with the large number of test pieces presently used.

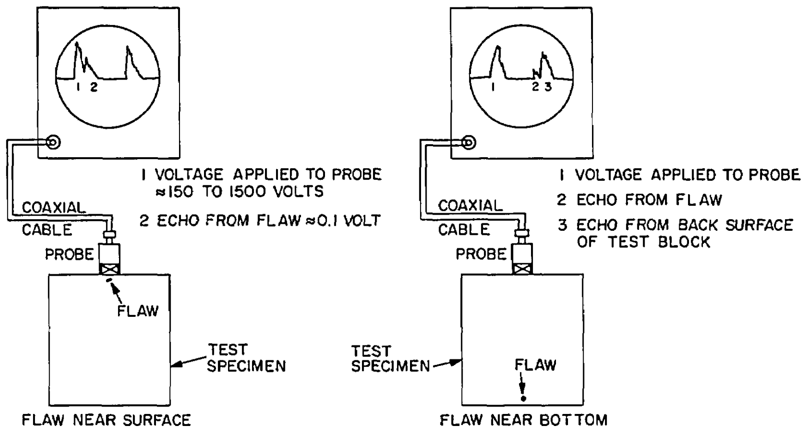

Fig. 10 - Two cases in which signals requiring resolution are of greatly different amplitude

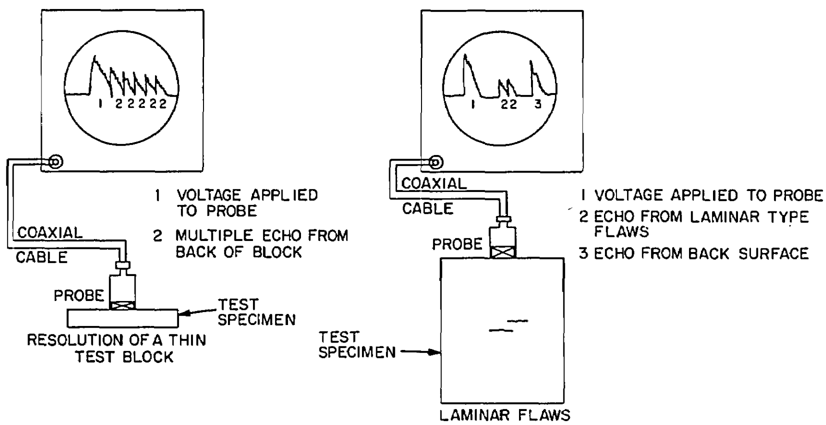

Fig. 11 - Two cases in which signals requiring resolution are of equivalent strength

PROPOSED FUNCTIONS FOR FUTURE ETB MODELS

At present we consider the ETB as a coordinate calibrator of ultrasonic equipment. Its use as a flaw size simulator is being investigated. Current practice is to use a test piece, of equivalent structural material to that being inspected, containing manufactured flaws whose dimensions and location are precisely known. In this manner a definite amplitude level is established for a given flaw area whose presence is anticipated in the material being inspected. Certain assumptions are normally made during such tests. One such assumption is that the flaw under examination has an orientation and reflective property similar to that of the test referral specimen.

For the ETB to operate in this mode, additional information concerning the wave propagation in a given material must be supplied. Evidence for the need of these requirements is shown in Fig. 1. Having placed a probe on the test specimen, the acoustic wave generated will propagate in accordance to the material characteristics. A flaw in the path of this wave will reflect that energy which has impinged on it. The returned energy is therefore not only a function of the pulse strength but also of the wave-front divergence, the reflector area, and the attenuation. Such information must therefore be preprogramed in this device. This being done, the signal amplitude sensed by the ETB's standard transducer can be properly processed and the return signal will convey information on flaw area.

Additional functions may also be performed with this device. The operating frequency of a probe can be determined by using a series of narrow-band standard transducers on the ETB. Also, a very small "point" standard transducer may be included in order to investigate the active operating area of a given probe. With this information, the expected divergence of the sonic wave may be calculated.

CONCLUDING REMARKS

An electronic device capable of replacing a multitude of cumbersome passive test blocks has been developed. This Electronic Test Block provides data concerning the behavior of commercial ultrasonic equipment. Both vertical and horizontal linearity as well as resolution can be visually monitored at the testing site, rather than at the laboratory, in a simple and efficient manner. This provides not only a saving in time and money but also increases the reliability of the inspection.

A number of serendipitous applications for this device are currently being investigated. Its use as a flaw size simulator appears to be feasible, especially so if certain probe parameters, such as active area and operating frequency, can be measured. Other future applications considered include the use of the ETB as an educational tool to train ultrasonic inspectors, a device to measure attenuation, and an ultrasonic spectrometer.

ACKNOWLEDGMENTS

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13. ABSTRACT

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Equipment calibration						
Transducer evaluation						
Nondestructive testing						
Flaws						
Structural materials						